

Composite Hot Drape Forming

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INTRODUCTION/APPROACH

This program was initiated to replace labor-intensive ply-by-ply layup of composite I-beam posts and angle stiffeners used in the Space Station Freedom (SSF) rack structure.

Hot drape forming (HDF) has been successfully implemented by BCAG for 777 composite I-stringers and by Bell Helicopter/Textron for the V-22 I-stringers. The two companies utilize two vastly different approaches to the I-beam fabrication process. A drape down process is used by Bell Helicopter where the compacted ply charge is placed on top of a forming mandrel and heated. When the heated ply charge reached a set temperature, vacuum pressure is applied and the plies are formed over the mandrel. The BCAG 777 process utilizes an inverted forming process where the ply stack is placed on a forming table and the mandrel is inverted and placed upon the ply stack. A heating and vacuum bladder underneath the ply stack form the ply stack up onto the mandrels after reaching the temperature setpoint.

Both methods have their advantages, but the drape down process was selected for SSF because it was more versatile and could be fabricated from readily available components.

CONCLUSION

The HDF process replaces labor-intensive hand layup of SSF I-beam posts and angle stiffeners with an effective and simple process. Ply wrinkling and other forming problems are virtually eliminated providing that the prepreg material outtime is minimized. The material outtime is especially critical on the glass/epoxy prepreg layers where "old" material can adversely effect the part surface quality. Two plies of FEP film and one ply of TFP cloth placed between the ply stack and the forming bladder provide multiple slick surfaces which allow the plies to smoothly form without wrinkles.

The problem of indexing the compacted ply stack to the forming mandrels has been solved by using nylon tooling pins to position the ply stack prior to forming. With metal forming mandrels, it is important that the control thermocouple be placed within the laminate and not placed on top of the ply stack or between the forming mandrel and the ply stack.

The HDF process has been selected for production of SSF composite rack components in which the I-beam posts and horizontal angle stiffener can be produced using the normal one step (one tool) process. The lower rear horizontal member (W-stiffener) and the joggled skin stabilizers are candidates for continued development using a two step (two tool) forming process

HOT DRAPE FORMER SET-UP

The developmental hot drape former was constructed from unistrut tubing and aluminum sheets to form a box-shaped hot drape fixture 108 X 54 X 84 inches with a 104 X 60 inch opening for a forming table. A rolling aluminum table with a 48 X 96 X 1 inch thick aluminum tool plate surface was constructed to roll parts into the fixture for forming (See Figure 1). The table's toolplate surface was covered with Richmond Toolcoat 807S Pressure Sensitive TFE fiberglass sheet for part release and to provide a slick surface to minimize bridging of the silicone forming bladder.

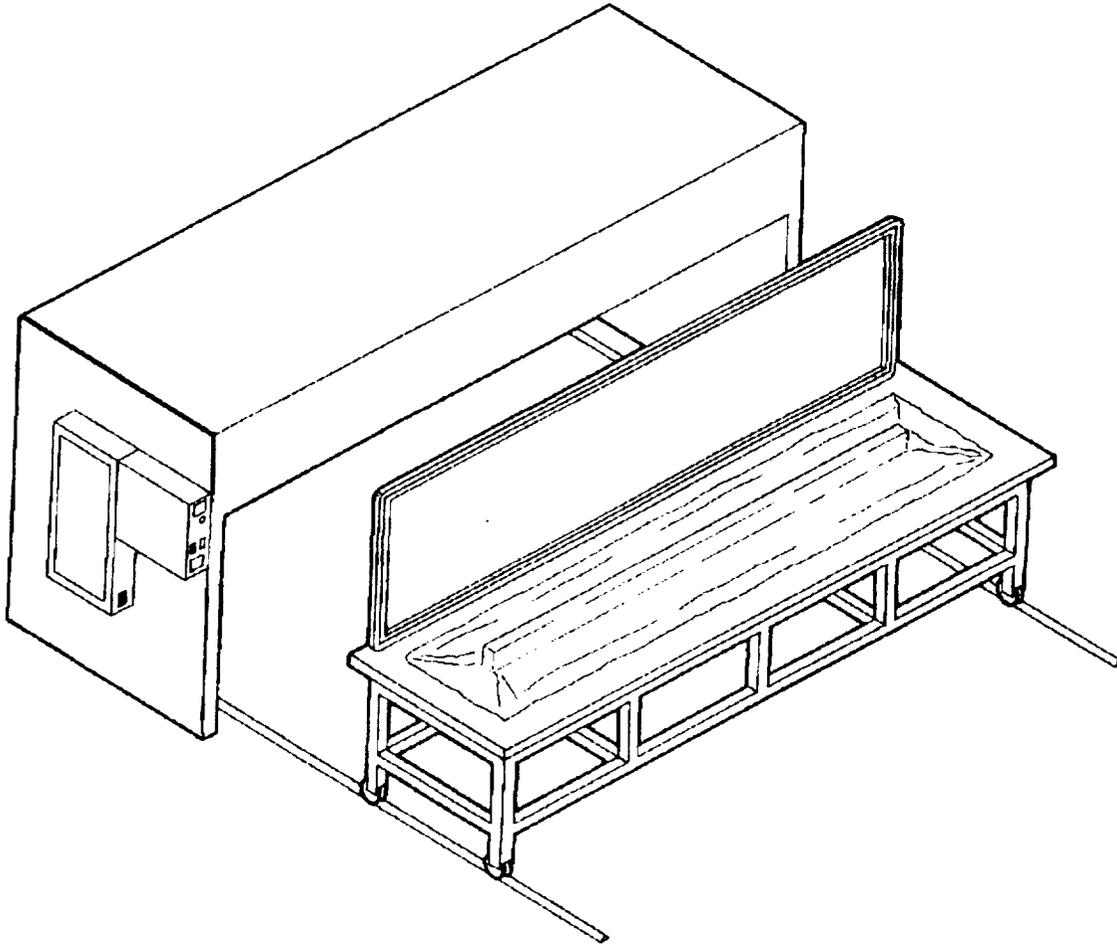


Figure 1 Hot Drape Forming Unit

Mosites Rubber Company fabricated the vacuum forming bladder using 2" aluminum box tubing, Mosites 1453-D silicone rubber sheet and a proprietary double bulb seal. The vacuum bladder utilized two vacuum ports with quick disconnect fittings to vacuum form the silicone rubber bladder, and one vacuum line to seal the frame and bulb seal to the tooling plate.

The heating was provided by using three banks of 480 volt, three phase infrared heaters controlled by a programmable digital controller. Feedback for the controller is provided using a J-type thermocouple placed in the composite ply stack excess trim area (at either end) during part forming (See Figure 2). To allow additional part temperature monitoring, capabilities a ten-channel switch and a digital temperature indicator was installed.

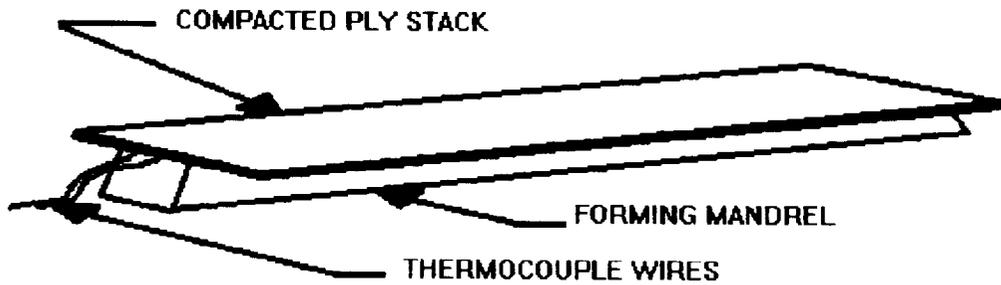


Figure 2 Thermocouple Wire Placement

PROCESS DEVELOPMENT

Process development consisted of forming 13 ply C-channels using developmental aluminum mandrels with a springback angle of 1.5 degrees to compensate for the original Developmental Rack I-beam post unsymmetric and unbalanced layup which were believed to cause excessive part springback.¹ The 13-ply forming charges were prepared by vacuum compacting (21" Hg minimum) ply stack then trimming out the 13-ply charge with a template and ultrasonic knife. The compacted ply stacks were indexed on the forming mandrels by cutting slots with an ultrasonic knife at each end of the ply stack, then pinning them to the mandrel using nylon tooling pins.

Vacuum tests showed that the vacuum bladder needed a slick surface to prevent bridging of the silicone rubber bladder and ensure that the plies form to the mandrels. A pad for the forming table was made from two plies of 10 ounce polyester breather cloth covered with a ply of TFP release cloth. To provide a slick surface over the part ply stack, two plies of non-perforated FEP film and one ply of 200 TFP-1 TFE coated glass fabric were placed over the compacted ply stack prior to forming (See Figure 3). The forming bladder was then lowered over the part, clamped into position, and the vacuum hoses connected. The table was rolled into the heating fixture, centered under the heaters, and the air draft curtain is closed.

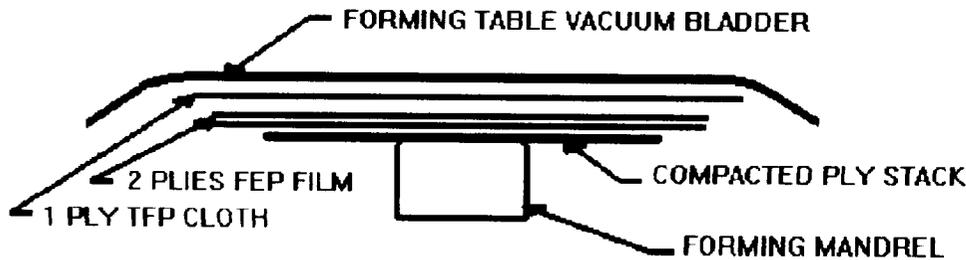


Figure 3 Part Preparation

The temperature control setpoint was set at 130° based on a process specification maximum of 150°F, and allowances for temperature overrun with the infrared heaters. The initial forming tests revealed a heat-up problem due to air drafts within the unit and the original location in a high bay fabrication area. To solve the draft problem, nylon vacuum bagging film was taped in place over the fixture openings, and welding curtains were placed around the unit. The draft problem was further solved by moving the hot drape fixture into a development clean room laboratory and installing a rubber seal strip to seal between the forming table and the heating unit. After removing

the draft problem, several developmental parts were formed including C-channels for I-beams or angle stiffeners, and multiple-flanged parts which would simulate a rectangular wing rib part or a five sided box.

Another process that was developed was two-step hot drape forming which involves forming an angle, removing it from the tool by inverting the angle and placing it on another tool to form opposite angles such as in a W-stiffener or Z-stiffener configuration (See Figure 4). The tool used in two step forming should be covered with a ply of FEP film to allow the part to be removed from the tool without damaging the part. The tool for the second step does not require FEP film unless the part requires transfer to a separate curing fixture. Alternatively a sheet of colored FEP or non-bondable Tedlar film can be incorporated into the ply stack and formed with the laminate providing good tool release later.

¹The flight rack design has changed to a symmetric and balanced layup which requires no springback allowance. Manufacturing Technology also recommends Invar steel mandrels for production to minimize the thermal coefficient of thermal expansion (CTE) differences between the part and tool, thus requiring only a minimum draft angle for part removal.

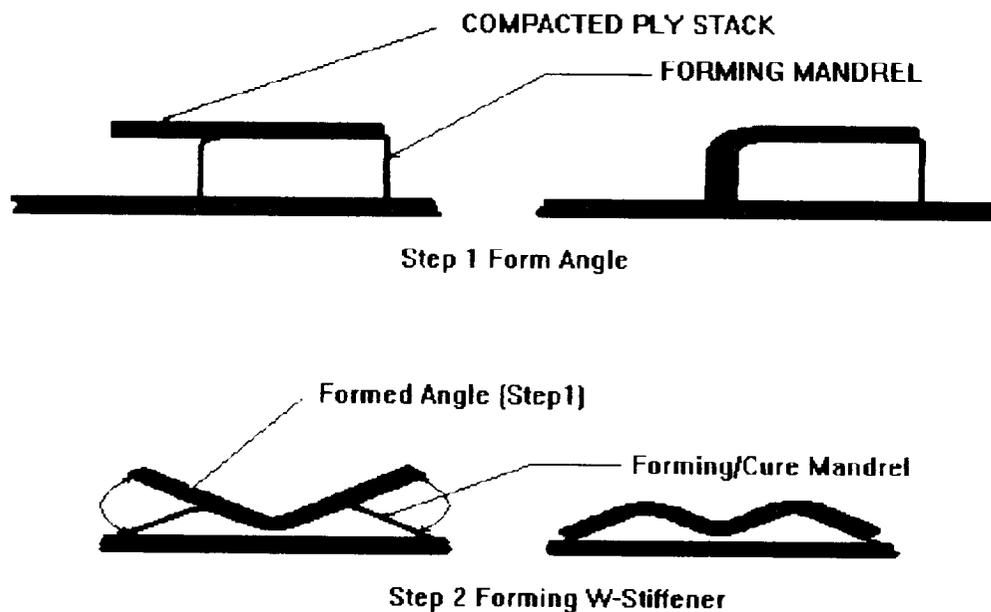


Figure 4 Two Step Hot Drape Forming

OPERATING PROCEDURES

A. Tool Part/Preparation

1. Lay-up and pre-compact laminate
2. Obtain the forming mandrel(s) and place on the forming table. Mandrel(s) shall be cleaned and treated with release agent.

3. Tape (Teflon or flash breaker tape) a J type thermocouple in the laminate at the mid-ply level. To allow additional monitoring, up to nine J type thermocouples may be placed in the laminate at the mid-ply level (preferred location) or taped to the tool surface. A minimum of one monitoring thermocouple per part shall be used (See Figure 2). All thermocouples used shall be placed in the part excess trim area.
4. Position the pre-compacted ply layup stack in position over the forming mandrel. Make sure the laminate is firmly located against the forming mandrel, and tape in place or secure using nylon tooling pins.
5. Cover the ply stack with two plies of non-perforated FEP film allowing 1-2 inches excess around the part periphery (See Figure 3).
6. Cover the FEP film layers with one ply of TFP cloth (Teflon coated fiberglass fabric). Trim the TFP cloth to 0.2 - 0.5 excess from the part periphery (See Figure 3).

B. Hot Drape Former Preparation

1. Turn on machine power, but do not turn on heaters.

Check controller temperature setpoint. Use a temperature setpoint between 120° and 140°F, with 130° ± 5° recommended by Manufacturing Technology.

2. Check the monitor or chart recorder to verify that each of the installed thermocouples is functioning properly.

C. Hot Drape Ply Forming

1. Position the forming table under the heaters.
2. Close the draft curtain or door on the front of the hot drape unit to expedite heating.
3. Turn on the heaters, and allow the ply stacks to warm up.
4. When the thermocouples indicate the ply stack temperature is 115-140°F, apply the vacuum to the tool assembly. Heat may be maintained if necessary for a maximum of five minutes, but do not exceed 150°F.
5. Turn off the heaters and move the tool to a cooling area. Allow the tool assembly to cool to 95°F or less. Maintain vacuum (15 inches/HG minimum) while the tool assembly is cooling.
6. Remove the vacuum source, vacuum bag, and release materials from the formed parts.
7. Inspect parts to make sure the plies are fully formed without any wrinkles. A properly formed part will tightly conform to the forming mandrel without wrinkles. Parts that do not appear to fully conform to the mandrel may be reformed.

CONCLUSION

The HDF process replaces labor-intensive hand layup of SSF I-beam posts and angle stiffeners with an effective and simple process. Ply wrinkling and other forming problems are virtually eliminated providing that the prepreg material out time is minimized. The material out time is especially critical on the glass/epoxy prepreg layers where "old" material can adversely affect the part surface quality. Two plies of FEP film and one ply of TFP cloth placed between the ply stack and the forming bladder provide multiple slick surfaces which allow the plies to smoothly form without wrinkles.

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HOT DRAPE FORMING CONCERNS

The primary concern with hot drape forming is ply wrinkling in the radius areas. The wrinkling problem was minimized by Engineering Design allowing fabric plies to be used in the $\pm 45^\circ$ ply orientations. The toolcoat covering on the mandrels, two plies of FEP film and one ply of TFP cloth collectively allow the compacted ply stack to smoothly form over the mandrels without wrinkles providing that the proper forming temperature is reached prior to the application of vacuum. The rate of vacuum application is also critical with some wrinkling problems noticed when vacuum was very slowly applied. To date, no problems have been encountered with a rapid application of vacuum.

Radius thin-out is another problem associated with HDF where the plies thin-out on the radius as a result of forming and/or curing. The C-channels formed for I-beams did not show any thin-out problems on cured I-beams, and the C-channels that were formed and cut into angle stiffeners showed a 0.001 - 0.003 inch thin-out on a 0.095 nominal part thickness. The all-fabric ply layup reduces the thin-out, and when problems occur, a rubber pressure pad is used to further minimize any radius thinning.

Non-destructive ultrasonic testing was conducted on formed C-channels, angles and I-beams. The only parts found to be unacceptable were made with materials that had excessive outtime.

PRODUCTION IMPLEMENTATION RECOMMENDATIONS

To prepare the developmental HDF for SSFP production several upgrades were required which included documentation, drawings and several fixture modifications. The modifications to the fixture include:

- 1) Design and fabrication of a new forming table with a hinged forming bladder. The table should also have drilled holes for thermocouple wire feed throughs and vacuum. To prevent vacuum leaks, the thermocouple wire holes should be potted with RTV silicone sealer.
- 2) Improved method to seal the table and the front opening of the heating unit (slide up door).
- 3) Temperature recording device for QA record of forming cycles.
- 4) Replace present miniature thermocouple jacks with the standard size jacks.
- 5) Convert present forming plate and bladder for use as a ply compaction table.
- 6) Wheel guides to positively locate table under the heaters. Metal angles bolted to the floor should serve as the necessary guide.
- 7) Provide grounding method which grounds forming table and unit to prevent static electricity shocks.

In addition to the fixture modifications, several other items are required for production implementation of the development hot drape former. These include calibration and certification of the controls (for temperature accuracy) and the heating system (for temperature uniformity).

Another suggestion for production would be to improve the ply stack indexing method by changing to Gerber cut slots or drilled holes rather than the present method of using a template and cutting slots with an ultrasonic knife.